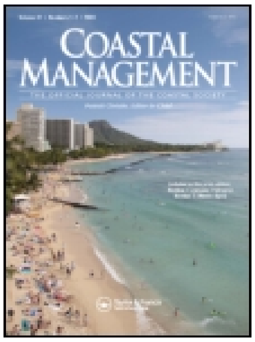

Coastal Management

ISSN: 0892-0753 (Print) 1521-0421 (Online) Journal homepage: https://www.tandfonline.com/loi/ucmg20

Coastal Erosion in Ghana: Causes, Policies, and Management

Fredrick Ekow Jonah, Emmanuel Abeashi Mensah, Regina Esi Edziyie, Nelson Winston Agbo & Daniel Adjei-Boateng

COASTAL MANAGEMENT
2016, VOL. 44, NO. 2, 116–130
http://dx.doi.org/10.1080/08920753.2016.1135273

Taylor & Francis
Taylor & Francis Group

Coastal Erosion in Ghana: Causes, Policies, and Management

Fredrick Ekow Jonah[a], Emmanuel Abeashi Mensah[b], Regina Esi Edziyie[c], Nelson Winston Agbo[c], and Daniel Adjei-Boateng[c]

[a]Department of Fisheries and Aquatic Sciences, University of Cape Coast, Cape Coast, Ghana; [b]Department of Geography and Regional Planning, University of Cape Coast, Cape Coast, Ghana; [c]Department of Fisheries and Watershed Management, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana

ABSTRACT

Coastal erosion is a serious problem that affects the safety and livelihoods of many coastal dwellers along Ghana's coast. Despite the fact that coastal erosion is a natural phenomenon, erosion trends have been largely aggravated by human-induced factors. This study analyzed shoreline change rates for three neighbouring coastal communities in the Central region of Ghana; Elmina, Cape Coast and Moree. Two epochs were analyzed, 1974–2012 (medium-term) and 2005–2012 (short-term), using ArcGIS and Digital Shoreline Analysis System. Overall, the entire study area recorded average shoreline change rates of -1.24 myear^{-1} and -0.85 myear^{-1} in the medium-term and short-term period respectively. Less consolidated shoreline segments recorded higher erosion rates in both periods while cliffs and rocky segments experienced very little erosion or high stability. Because shorelines undergoing chronic erosion do not fully recover after short-term erosion events such as storms, facilities located close to such shorelines are threatened. Taking a proactive approach to coastal erosion management, such as coastal sand mining prevention, inter-sectoral land use management and adopting a construction setback approach may be prudent for the long-term management of the coast since this recognizes future shoreline changes and safeguards coastal landscape for other uses.

KEYWORDS
climate change; coastal erosion; coastal management; shoreline change

Introduction

Coastal areas have been vital to economies the world over because of their multiplicity of use and the resources that are obtained there. About a billion of the world's population live within 100 kilometers of the coastline owing to coastal resources (Kurt, Karaburun, and Demirci 2010). Due to the attractiveness of the coast, there has been a disproportionately rapid expansion of economic activities (Nicholls et al. 2007), leading to the conversion of most of the world's natural coastal landscapes such as deltas, barrier islands, beaches, and estuaries into agriculture, silviculture, aquaculture, industrial, and residential uses (Valiela

CONTACT Daniel Adjei-Boateng adjeibd@gmail.com Department of Fisheries and Watershed Management, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana.

Color versions of one or more of the figures in the article can be found online at www.tandfonline.com/ucmg.

2006). In many cases, these intense utilization and conversion of coastal resources have contributed to the erosion and retreat of coastlines (Mackenzie 2003), which is now regarded as a global issue (Cai et al. 2009).

In West Africa, the effects of urbanization and the high concentration of industrial and commercial activities along the coasts have resulted in an unprecedented exploitation of coastal resources such as coastal sand, mangrove forests and estuaries (Mensah 1997). Key industries, major residential settlements, tourism and conservation sites, heritage and historical monuments are located within 200 m of Ghana's coastline with many of the most densely populated coastal communities located in low-lying coastal plains susceptible to coastal flooding (Boateng 2006). In the last couple of decades, many of these coastal communities have become threatened by sea waves. Several major sea defence projects have been undertaken by the central government along the most affected communities to protect infrastructure and assets of national interests. Other small scale sea defence projects have also been carried out by property owners along many sections of the country's coast with the view to protect their investments (Jonah et al. 2015).

Climate change, particularly accelerated sea-level rise, is expected to exacerbate erosion problems (IPCC 2014), requiring effective management strategies in dealing with the risks arising from coastal erosion (Appeaning Addo, Walkden, and Mills 2008). An effective coastal erosion management strategy relies on knowledge and information about historic shoreline location and movement (Appeaning Addo, Walkden, and Mills 2008). In most developing countries however, shoreline data are scarce or scanty (Appeaning Addo, Walkden, and Mills 2008), presenting a major challenge to coastal planners and scientists when determining historical rates of shoreline change and trends for decision-making.

For coastal management purposes short-term events often represent a far greater hazard to infrastructure than medium to long-term trends and hence, it is reasonable to assume that in order to support decision-making mechanisms, a better understanding of the relationship between storms, sand budget, and beach erosion is necessary (Esteves et al. 2002). A short time period of shoreline position and beach volume assessment is carried out at small spatial scales in periods less than 10 years (Anfuso, Domingue, and Gracia 2007) while shoreline change analysis done within 10 and 60 years can be considered as medium term (Jimenez and Sanchez-Arcilla 1993).

In this article, an analysis of shoreline changes in two epochs, that is, 1974 to 2012 (medium term) and 2005 to 2012 (short term) for the Elmina, Cape Coast, and Moree coastlines of Ghana are presented. Prior to 1974, this area was identified to be stable (Ly 1980). Urbanization of Ghana's coast was thought to have increased from the early 1970s coinciding with the exploitation of large amount of coastal resources such as sand and stones to feed the construction industry (Dei 1972). This study is relevant as it adds to the global database and literature on historical shoreline changes. This study also documents the changes that have occurred to this shoreline since active urbanization began and also presents the challenges faced in managing coastal erosion in a country that is in the early stages of developing a shoreline management program.

Materials and methods

Study area

The study was conducted along three coastal communities; Elmina, Cape Coast, and Moree in the Central Region of Ghana, which is on the Gulf of Guinea (Figure 1). The coastlines studied are about 25 km in length and lies between latitude 05°07′50.0″N and longitude 001°38′20.0″W (Elmina) and latitude 05° 13′91.2″N and longitude 001°19′07.4″W (Moree). This area has an equatorial climate, characterized by wet and dry seasons, and is influenced by the southwest monsoon winds.

The area has annual average minimum rainfall of 24 mm and highest of 327 mm. The geology of the area comprises: the Elmina zone which is mainly sandstones and grits, Cape Coast is made up of granitiods and a few sandstones while Moree zone is of phyllite and schist (Minerals Commission Ghana 2011). All the zones share similar vegetation cover (grasslands and coastal thickets) and soil type (acrisols). The coast is made up of medium energy waves averaging 1 m in the surf zone, with net direction of alongshore waves in the easterly direction (Jonah 2015), while wave periods range from 5.1–5.3/minutes. Littoral sediment is mainly derived from marine sources, even though there is some amount of sediment flow to the coasts through riverine and lagoonal sources.

Coastal development is mainly confined to the main townships of Elmina, Cape Coast and Moree, with infrastructure built on beach dunes landwards. Some tourism and residential facilities are also sparsely located along the undeveloped segments of this coastline. Several beach-front tourism facilities located in this area have been reinforced with sea defense

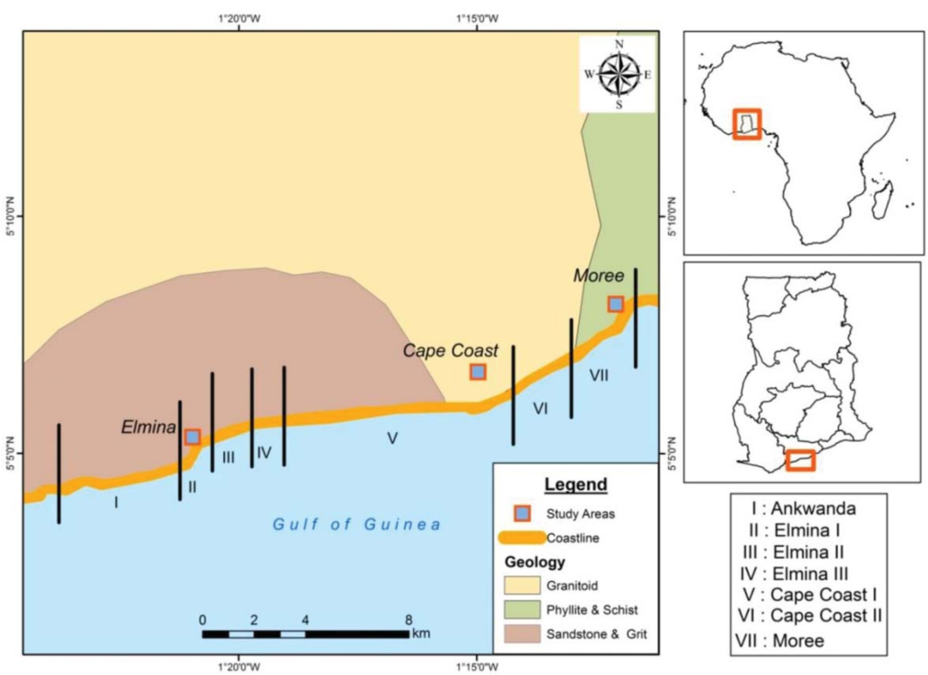

Figure 1. Map of Ghana showing the Elmina, Cape Coast, and Moree coastline.

walls. Three freshwater systems flow into the coast, that is, the Kakum River, the Fosu Lagoon (a closed lagoon with occasional breach of the sand bar to join the sea), and the Benya lagoon. The Benya lagoon, located in Elmina, has been dredged, expanded, protected with a jetty and developed into a fishing harbor.

The study area was divided into seven segments for easy analysis of the shoreline change results. This division was done based on the orientation and coast type as shown in Figure 1: The divisions are; Ankwanda, Elmina I, Elmina II, Elmina III, Cape Coast I, Cape Coast II, and Moree.

Historical shoreline change analysis

Short-term and medium-term shoreline changes were determined by using ArcGIS and Digital Shoreline Analysis System (DSAS: Thieler et al. 2009) tools. The shoreline data used included a digital scan of a 1974 topographic survey map, a 2005 shoreline obtained by visually tracing the shoreline from a 2005 orthophotograph and a 2012 shoreline obtained through a shoreline tracking survey using a Garmin 60Cx GPS device. The GPS device used had a spatial accuracy of 3 m. The 1974 digital topographic shoreline data and 2005 orthophotograph shoreline were both obtained from the Survey Department of Ghana.

The high water line (HWL) proxy was used to define all shoreline positions in all three shoreline data. The HWL is the highest run-up of the last high tide, identifiable on orthophotographs and on the beach by the visually discernible wet/dry line (Pajak and Leatherman 2002; Boak and Turner 2005). The HWL proxy is generally deemed as a valid indicator of shoreline position (Gorman, Morang, and Larson 1998) and may sometimes be the only indicator available, especially in highly developed coasts where the beach is backed by a seawall, riprap revetment or other artificial structure (Del Rio and Gracia 2012).

For the 2005 shoreline data, using the orthophotograph in ArcGIS, the HWL was identified at one end of the study area and carefully traced at a scale of 1:1500 to obtain the shoreline for that year. The 2012 shoreline was acquired by first identifying the HWL at one end of the study area and following it across the entire stretch to capture the shoreline data for that year.

All the shorelines were projected into the same coordinate system, Ghana Meter Grid projection. The shorelines were compiled and appended into a single feature class in ArcGIS which enabled the calculation of change statistics using DSAS. A baseline was created onshore parallel to the time series of shorelines at a distance of 100 m. The baseline closely followed the direction of the outer shoreline, which enabled transects to be cast perpendicular to the general direction of the shorelines.

Transects were cast 20 m apart and were 160 m in length from the baseline, which enabled transects to intersect with all the shoreline vectors. The points of intersection provided location and time information which were used to calculate rates of change for the two epochs. DSAS was then used to generate the shoreline change rate statistics using the Linear Regression Rate and End Point Rates statistics. Figure 2 shows the procedure that was followed in DSAS to generate the rate of change statistics in ArcGIS.

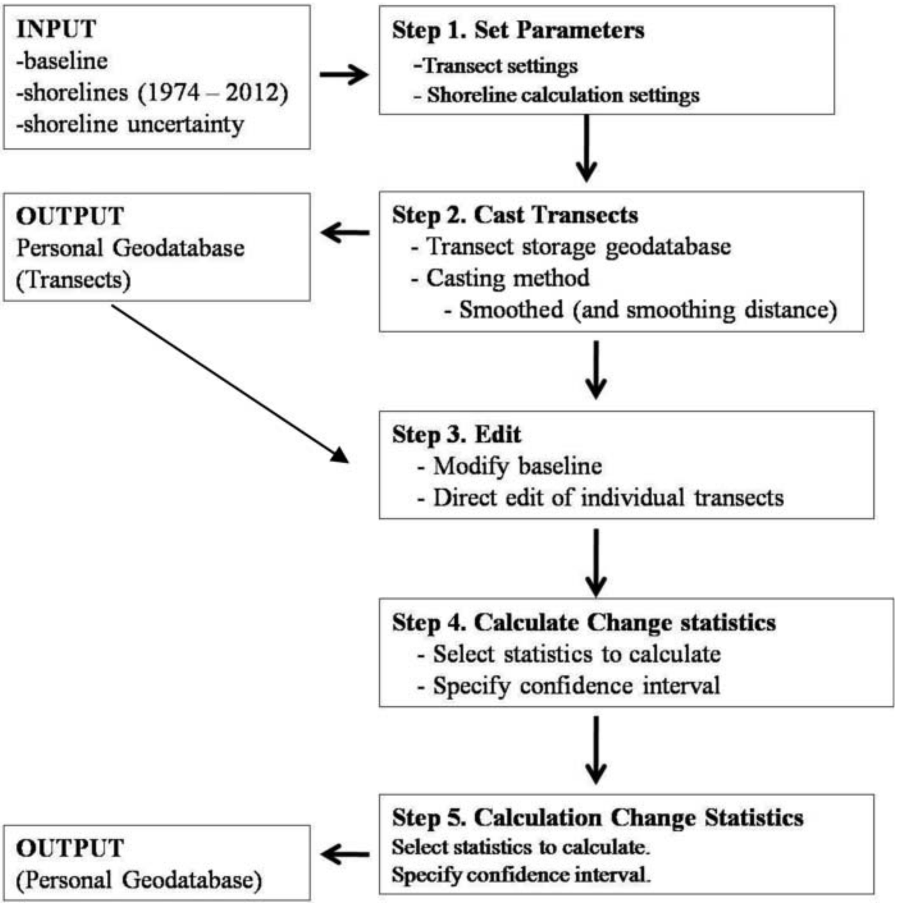

Figure 2. Shoreline change analysis procedure in DSAS (Thieler et al. 2009).

Error margin determination

According to Morton, Miller, and Moore (2004), documented trends and calculated rates of shoreline change are only as reliable as: (1) measurement errors that determine the accuracy of each shoreline position, (2) sampling errors that account for the variability of shoreline position, and (3) statistical errors associated with compiling and comparing shoreline positions. This study used error estimates based on Hapke et al. (2010). We deemed four uncertainty terms from Hapke et al. (2010) to be relevant to this study: georeferencing uncertainty (U_g), digitizing uncertainty (U_d), aerial photo uncertainty (U_a), and the uncertainty of the high water line at the time of survey (U_{pd}). These values are presented in Table 1 to show how each error contributes to uncertainty in the rates of change. In addition to these, we associated another uncertainty value, GPS device spatial accuracy (U_s), to the 2012 shoreline.

For each shoreline position, U_p, the total uncertainty is found as the square root of the sum of squares (Taylor 1997; Hapke et al. 2010) of the relevant uncertainty terms [Equation (1)]. Specific shoreline uncertainty errors are also presented in Table 1. These individual uncertainty values were used to calculate annualized uncertainty values at each transect. The uncertainty of a single transect's end point shoreline change, U_E rate is found as the

Table 1. Errors associated with the datasets used in this study.

Measurement errors (m)	Digital map (1974)	Aerial photo (2005)	GPS field survey (2012)
Georeferencing uncertainty (U_g),	4	—	—
Digitizing uncertainty (U_d),	1	1	—
Aerial photo uncertainty (U_a)	—	3	—
Uncertainty of the High Water Line (U_{pd})	4.5	4.5	4.5
GPS device spatial accuracy (U_s)	—	—	3
Total shoreline position uncertainty (U_p) (m)	6.10	5.5	5.41

quadrature addition of the uncertainties for each year's shoreline position, divided by the number of years between the shoreline surveys [Equation (2)].

$$U_p = \sqrt{U_g^2 + U_d^2 + \ U_a^2 + \ U_{pd}^2 + \ U_s^2} \tag{1}$$

$$U_E = \frac{\sqrt{U_1^2 + U_2^2}}{year2 \ - \ year1} \tag{2}$$

where U_1 and U_2 are the total coastline position error for each year.

This approach carries the reasonable assumption that the component errors are normally distributed (Appeaning Addo, Walkden, and Mills 2008). The calculated annualized errors for each epoch are presented in Table 2. The maximum error estimated for the medium-term period in this study was found to be ± 0.26 myear^{-1}, while the annualized error estimated for the short-term period is ± 0.96 myear^{-1}.

Results

Trends in shoreline changes

From 1974–2012, the Elmina–Cape Coast–Moree area recorded a linear regression rate (LRR) of -1.24 myear^{-1} $\pm$ 0.26 m. In the medium-term period (1974–2012), the highest and lowest LRR's were recorded for the Cape Coast I and Moree segments, respectively. Most sections of the Cape Coast I shoreline segment recorded LRR's exceeding -1.50 myear^{-1} with very few areas recording erosion rates lower than -1.50 myear^{-1} (Figure 3). Ankwanda, Elmina I, and Elmina III shoreline segments predominantly recorded LRR's below -1.50 myear^{-1}, with a few areas recording rates higher than -1.50 myear^{-1}, while for Elmina II segment, recorded LRR's were all below -1.50 myear^{-1} (Figure 3). Within Cape Coast II segment, there were a few areas that showed either stability or accretion even though there was predominant erosion mostly below -1.50 myear^{-1} with a few areas exceeding -1.50 myear^{-1}. The Moree segment mostly recorded LRR below -1.50 myear^{-1} with some areas experiencing either accretion or stability. The accretion or

Table 2. Calculated errors at each transect for the medium- and short-term periods.

Period	Annualized error (m/yr)
1974–2012	$\pm$ 0.26
2005–2012	$\pm$ 0.96

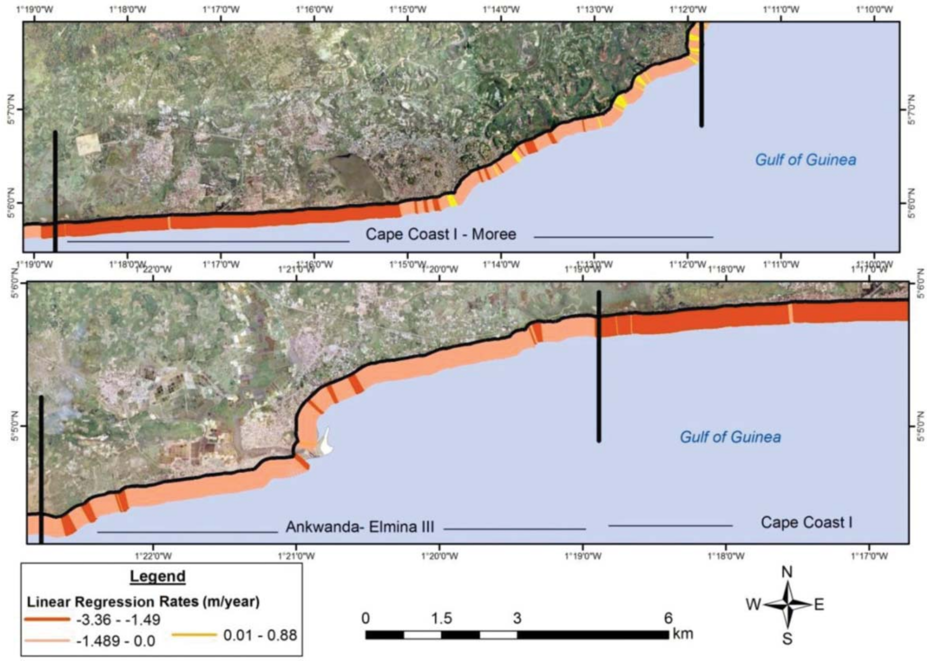

Figure 3. Recorded linear regression rates for the Elmina–Cape Coast–Moree area during the period 1974–2012.

stability of some areas of Cape Coast II and Moree shoreline segments were recorded at cliff and predominantly rocky areas. A summary of LRR and End Point Rate (EPR) recorded for the 1974–2012 and 2005–2012 periods are presented in Table 3. The trends in LRR for the 1974–2012 period is shown in Figure 4.

Short-term EPR for the Elmina–Cape Coast–Moree shoreline (2005–2012) was -0.85 myear^{-1} $\pm$ 0.96 m, lower than that recorded for the medium-term period. The Ankwanda, Cape Coast II, and Moree shoreline segments however recorded higher short-term EPR erosion rates than were recorded in the medium-term period (Table 3). The trend in EPR for the 2005–2012 period is shown in Figure 5.

Variability in uncertainty values

The uncertainty associated with the recorded shoreline change rates for the medium- and short-term periods are presented in Table 2. These uncertainty values are as a result of the type of shoreline datasets used in the extrapolation of rate of change statistics. Moreover,

Table 3. Net medium-term (1974–2012) linear regression rates and short-term end point rates (2005–2012) for the Elmina, Cape Coast, and Moree coastlines.

Sub-region	Ankwanda	Elmina I	Elmina II	Elmina III	Cape Coast I	Cape Coast II	Moree
LRR (1974–2012) ±0.26 m	−1.16	−1.34	−0.99	−1.45	−2.01	−1.06	−0.69
EPR (2005–2012) ±0.96 m	−0.96	−0.14	−0.82	−0.92	−0.93	−1.29	−0.86

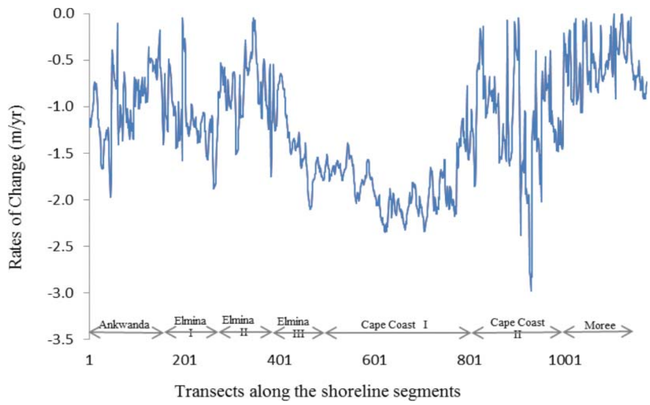

Figure 4. Medium-term (1974–2012) linear regression rates for the Elmina, Cape Coast, and Moree area.

uncertainty in shoreline change rates is higher for the short-term period because it uses less data and over a shorter period of analysis.

Discussion

Causes and reasons for coastline changes

The lower rate of change and overall percentage of coastline erosion experienced in the short-term period of analysis may be attributed to short-term variations in coastal processes such as waves, tides, storm surges, run-up (Dolan et al. 1980), and longshore sediment transport (Esteves et al. 2002).The shoreline is a time-dependent phenomenon that may exhibit substantial short-term variabilities (Morton 1991) and hence for coastal erosion management purposes, short-time events can represent a far greater hazard than long-term or medium-term trends (Esteves et al. 2002) and require a proper understanding of coastal and weather dynamics to properly address them. This is because short-time erosion events have

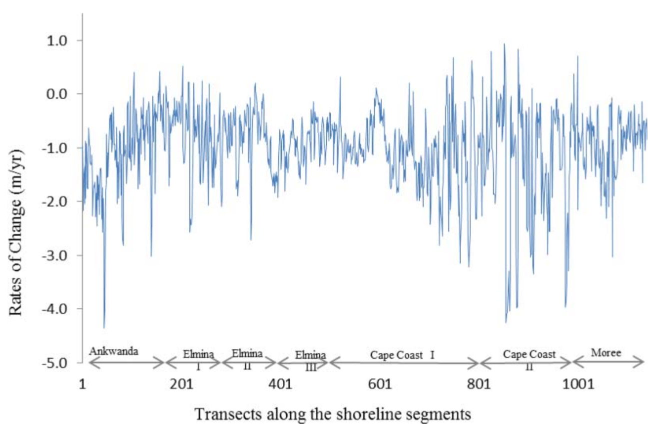

Figure 5. Short-term end point rates (2005–2012) for the Elmina, Cape Coast, and Moree area from 2005–2012.

Figure 6. Examples of degraded small scale beach front sea defence projects along the Elmina–Cape Coast–Moree area of Ghana, (A) and (B) are in Elmina, (C) Erosion is near Cape Coast.

the potential of impacting dune features through over wash, diurnal tidal activities, or coastal flooding and inundation as a result of storm surges. Examples of impacts of short-time erosion events on facilities are widespread along the coast of Elmina, Cape Coast, and Moree (Figure 6). These short-term erosion events in the Elmina, Cape Coast, and Moree area can also be observed through the nature of beach morphology. These include short-term formation of erosion scarps, steep sand bar formation in some areas, and periodic exposure and covering of underlying beach rocks. Such short-term events have usually become a problem needing some form of management intervention as a result of facilities located nearby. Along shoreline sections where no facilities exist, these short-term events are not a problem.

In the medium term, the net linear regression rate trends observed for the Elmina, Cape Coast, and Moree area are slightly higher than trends for the Accra coast recorded by Appeaning Addo, Walkden, and Mills (2008). This study recorded an erosion rate of -1.24 myear^{-1} ± 0.26 m while the long-term shoreline change rate for Accra was -1.13 myear^{-1} ± 0.17 m. The slight differences in net erosion rate for these two areas with similar geomorphological features and land uses (Oteng-Ababio, Owusu, and Addo 2011) and just about 100 km apart could be a result of the difference in time spans of the datasets used in analyzing shorelines. This shows that erosion along Ghana's coast is not only confined to the Elmina, Cape Coast, and Moree area, but to other sections of the country's coast.

Factors that control coastal erosion include shape and location of the beach (Alonso, Alcántara-Carrió, and Cabrera 2002; Oteng-Ababio, Owusu, and Addo 2011), relative sea-level change, wave energy, sediment supply (Pilkey and Thieler 1992; Alonso, Alcántara-Carrió, and Cabrera 2002), and net longshore drift. Boateng (2006) reported that the net longshore drift for the Elmina, Cape Coast, and Moree coastline is from west to east. Though the entire coastline of Elmina, Cape Coast, and Moree is continuous and under similar conditions of influence, changes along the Cape Coast I segment were consistently high in both analyzed periods. The Cape Coast I segment is without headlands that may act to contain sand within embayment and hence more vulnerable to erosion. The other six segments have sandy beaches interspersed with rocky projections or cliffs at various alternating lengths and hence may account for the lower erosion trends. Sandy beaches are made up of unconsolidated sediment and are more easily influenced by currents, tides and waves. Hence, it was probably easier for sediments to have been carried along and outside of Cape Coast I segment under natural conditions compared to the other segments where rocks or cliff areas could have resisted the movement of sediments by natural factors (or helped trap sediments and keep them from leaving the littoral cell thereby limiting erosion rates). Additionally, sandy beaches are likely to have higher human use than the other stretches.

Tomazelli et al. (1998) observed that lagoon systems trap sediment from fluvial discharge, reducing the sand volume reaching the shore, the erosion rates at the Cape Coast I could have been influenced by the Fosu lagoon trapping shore bound fluvial sediments for most parts of the year, thus starving the area of vital sediment for use in coastal processes.

The Elmina I segment recorded a medium-term change rate of -1.34 m year^{-1} ± 0.26 m in conformity with the average medium-term change rate of the entire coastline during this study, but recorded the lowest change rate in the short-term period. The explanation for this short-term trend could most likely be found in the jetty that was constructed in the mid-2000s to protect the Elmina fishing harbor on the Benya lagoon. Because of the characteristic dome shape of the segment, the jetty protrudes across the face of the shoreline and most likely deflects the energy of incoming waves allowing gentler and less harmful waves to get to the shore. Sediments within the segments were most likely trapped and re-circulated.

In the short-term period, Ankwanda, Cape Coast II, and Moree shoreline segments had erosion rates exceeding the average for the period (Table 3). Short-term erosion rates for Cape Coast I and Moree exceeded their respective medium-term rates while rates at Ankwanda decreased during the short-term period. The highest recorded erosion at an individual transect occurred at the Cape Coast II during the medium-term period (Figure 4). Also, extremely high erosion rates were experienced at some individual transects within the Ankwanda and Cape Coast II during the short-term period (Figure 5). These excessive localized erosion rates experienced within these three shoreline segments during the medium-term and short-term periods are most likely a result of the intensive commercial beach sand mining operations identified to be carried out on those specific beaches by Jonah et al. (2015). Coastal sand mining has been identified to accelerate coastal erosion (Carter 1991; Mensah 1997; Wong 2003).

Current coastal management regimes in Ghana

The problem of coastal erosion and human related causes are not unique to Ghana, but has been a subject of interest in many coastal nations around the world. Along the Mediterranean coasts, Sanjaume and Pardo-Pascual (2005) identified human actions such as sand and gravel mining from rivers and beaches, building of dams, jetties, and breakwaters and destruction of littoral dunes to build facilities as the main drivers of beach erosion. At the northeast Bohai Sea of China, damming of rivers, coastal engineering, and tourism activities were identified as having intensified coastal erosion (Xue et al. 2009). Along the Puerto Rican coast, hundreds of shoreline stabilization projects have been carried out to protect buildings; however, these have also been identified to have accelerated erosion elsewhere along the coast (Neal et al. 1995). In the United States, riverine, beach, and dune sand and gravel mining along the Monterey Bay of California in the 1970s have been associated with erosion along that coast (Magoon et al. 2004; Thornton et al. 2006). However, in most of these areas, significant successes have been achieved in controlling coastal erosion by mainly limiting human activities within the active coastal zone.

In Ghana, there is still no holistic policy or integrated plan for the management of coastal erosion and flooding (Boateng 2006). The current 2014 National Environmental Policy does not include clear cut action plans but only recognizes the need to manage the marine and coastal zone. This has caused management to continue to remain traditional, reactive, site specific, and dominated by hard engineering approaches, which are fraught with their own peculiar problems to the coastal environment.

Along most sections of Ghana's coast, the mere threat of a retreating beach is enough to elicit a management response from investors such as tourist facility owners. These interventions are usually in response to short-term erosion events that usually threaten facilities located close to the eroding beach. In most cases, coastal management is regarded as a matter of protecting each individual's properties and does not require the acquisition of special permits from municipal authorities. Usually, little or no studies are conducted to determine and minimize possible effects of such projects on the wider coastal environments, except in larger community-wide coastal defense projects that are undertaken by the central government. However, because rapid trends in erosion during specific natural events are part of the natural coastal dynamics (Carter 1991); there should be an understanding of these processes to inform management decisions as to the appropriate interventions to adopt. In most cases, engineers are more concerned with the stability of the human-built structures, their discrete function and design than their effects on the wider geomorphological, ecological, and recreational values of the beach. Such hard structures tend to aggravate erosion rates and cause the failure of those structures (Figure 5).

The flexibility of beaches in the Elmina, Cape Coast, and Moree area have been limited, causing the loss of beaches fronting shoreline structures. This "coastal squeeze" is as a result of increased and poorly planned development and urbanization along the terrestrial side of the coastline and increased wave run-up and over wash by the sea. When unconstrained, beaches are resilient, changing shape and extent naturally in response to storms and variations in wave climate and currents (Schlacher and Thompson 2007).

Alternative management strategies

Climate change and sea-level rise events are expected to influence trends in coastal erosion along coastal nations (IPCC 2014). Making coastal land use decisions that will ensure that interventions will not be needed in the future to protect structures, however, may be the most prudent coastal erosion management solution, by ensuring that development remains at a relatively safe distance from the shoreline. These decisions could be incorporated into both national and local level policies. One approach could be to use coastal erosion rates determined over a suitable time interval as the basis for building setbacks, as is done in several U.S. states (e.g., North Carolina and Michigan) (NRC 1990). This option is explained further below. At the local government level, metropolitan, municipal, district assemblies (MMDAs) in Ghana have the responsibility of enforcing and protecting the environment within their jurisdiction. Coastal MMDAs have mandates that include management of coastal resources and infrastructure that can be achieved through enforcement of enacted bye-laws and regulations. The following are suggestions that could be incorporated into both national and local level policies to ensure proper coastal management and control of erosion.

Construction setback

The effects of coastal erosion can be countered by simply keeping structures back. A retreating beach simply changes its position in space as it migrates, maintaining the same general appearance as before (Fletcher, Mullane, and Richmond 1997). Fletcher, Mullane, and Richmond (1997) observed that if the adjoining land is composed of sand, coastal erosion creates little problem for the beach because it uses this sand to sustain the environment. However, when there are buildings and other infrastructure such as roads built very close to the coast, they come into conflict with natural coastal dynamics. The prudent planner will build well back from the shoreline or shore bluff, recognizing that some erosion is likely to occur over the years (Neal et al. 1995). A setback line is delineated at a calculated distance inland from the beach, and all construction is required to be located landward of this line (Clark 1998).

The setback distance is calculated using a methodology that predicts how far back the beach will erode in the future. Calculation of setbacks can be done by using average annual recession rate and multiplying it by the number of years that planning is being made for (NRC 1990). The resulting value may be adjusted slightly for recession rate variability within an area by adding a safety factor multiplier. Calculation of setbacks assumes that long-term erosion rates will continue to be approximately the same in the future as they have been in the past (NRC 1990). This makes the results obtained in this study very useful, as it can be used to delineate a construction setback for the area under study.

In Ghana, coastal MMDAs can use this technique to calculate the minimum setback distances based on local conditions to determine where to put up new buildings or facilities as part of their building regulations. In several case studies along Ghana's coast, Boateng (2012) observed that high rates of coastal recession had not affected coastal development in some areas due to large coastal buffer land that exist between the coastline and developments. Adopting a construction setback approach will not only protect properties but also promote the tourism industry by preserving coastal landscapes and beaches that are important for tourism. Such an approach could also save the central government and facility-owners substantial monies that would potentially go into coastal sea defence projects.

Coastal sand mining enforcement

Coastal sand mining has been identified to be widespread along most stretches of Ghana's coastline (Mensah 1997; Boateng 2006; Jonah et al. 2015). Although illegal, these have largely been disregarded as a major cause of coastal erosion especially by those involved who view the activity as a viable economic venture for the youth in some communities. However, the contribution of beach sand mining to coastal erosion has also been noted by several authors in Ghana (Mensah 1997; Boateng 2006, 2012; Appeaning Addo, Walkden, and Mills 2008; Oteng-Ababio, Owusu, and Addo 2011; Jonah et al. 2015). If coastal erosion trends are to be controlled, it is necessary that coastal MMDAs take up enforcements activities seriously. These could be done by collaborating with the Ghana Police Service and the Environmental Protection Agency, who are stakeholders in environmental protection. If coastal sand mining activities are not controlled, the rate of coastal erosion will continue to increase and sea defense measures will continue to fail.

Inter-sectorial land use management

Several land use activities that occur inland, sometimes several kilometers away from the coast, tend to influence the rate of coastal erosion. Rivers and streams are important sources of sediments to the coastal environment (Chen and Chen 2002; Boateng 2006; Cai et al. 2009). However, several land use activities upstream tend to interfere with the flow of rivers leading to a reduction in the volume of sediments that ultimately reaches the coast, and resulting in an increased rate in coastal erosion. It is therefore essential that contemporary land use planning procedures take into account the multiple stakeholders that will ultimately benefit or suffer from such activities. Upstream land use activities such as dam construction, river abstraction for agriculture, river basin management, and so on, spans ministerial, sectorial, and district boundaries and must therefore be considered in an integrated context by a team of inter-sectorial experts.

Conclusions

This study showed that the entire Elmina, Cape Coast, and Moree coastline has been eroding since 1974. Erosion was observed to be higher along shorelines consisting of unconsolidated or poorly consolidated sediments. Human related factors that may be driving erosion trends in the area include beach sand mining, building within the active coastal zone and poorly executed small scale engineering interventions.

The lack of an existing coastal zone management policy or coastal erosion management plan for Ghana's coast makes effort to control the hazards of erosion ad hoc and localized. Most engineering interventions along the Elmina, Cape Coast, and Moree area have been unsuccessful and may probably have contributed to nearby shoreline retreat. Because of the variability in coastal processes, planning for coastal intervention must not be taken lightly. Engineers and coastal managers need to have an in-depth understanding of natural coastal dynamics before they make decisions on the type of interventions to implement. Moreover, it may be prudent for coastal planners to realize that erosion may occur in the future and hence should build well behind the actual shoreline. Adopting such proactive approaches to coastal erosion management will allow for the evolution of the coastline and tourist to continue to enjoy the natural coastal landscapes.

Acknowledgment

The authors greatly acknowledge the contribution of Mr. Osman Adams during the fieldwork, GIS analysis, and his input into the final write-up.

References

Alonso, I., J. Alcántara-Carrió, and L. Cabrera. 2002. Tourist resorts and their impact on beach erosion at Sotavento Beaches, Fuerteventura, Spain. *Journal of Coastal Research* 1–7.

Anfuso, G., L. Domingue, and F. J. Gracia. 2007. Short and medium-term evolution of a coastal sector in Cadiz, SW Spain. *Catena* 70(2):229–242.

Appeaning Addo, K., M. Walkden, and J. Mills. 2008. Detection, measurement and prediction of shoreline recession in Accra, Ghana. *ISPRS Journal of Photogrammetry & Remote Sensing* 63:543–558.

Boak, E. H., and I. L. Turner. 2005. Shoreline definition and detection: A review. *Journal of Coastal Research* 21 (4):688–703.

Boateng, I. 2006. Shoreline management planning: Can it benefit Ghana? A case study of UK SMPs and their potential relevance in Ghana. *Promoting Land Administration and Good Governance, 5th FIG Regional Conference*, Accra, Ghana, March 8–11, 2006.

Boateng, I. 2012. An application of GIS and coastal geomorphology for large scale assessment of coastal erosion and management: A case study of Ghana. *Journal of Coastal Conservation: Planning and Management*, doi:10.1007/s11852-012-0209-0

Cai, F., X. Su, J. Liu, B. Li, and G. Lei. 2009. Coastal erosion in China under the condition of global climate change and measures for its prevention. *Progress in Natural Science* 19:415–426.

Carter, R. 1991. Near-future sea level impacts on coastal dune landscapes. *Landscape Ecology* 6 (1/2):29–39.

Chen, J. Y., and S. L. Chen. 2002. Estuarine and coastal challenges in China. *Marine Geology Letters* 18 (1):1–5.

Clark, J. R. 1998. Coastal seas, the conservation challenge. Malden, MA: Blackwell Sciences.

Dei, L. A. 1972. The central coastal plains of Ghana: A morphological and sedimentological study, 2. *Geomorphology* 16:415–431.

Del Río, L., and F. J. Gracia. 2012. Error determination in the photogrammetric assessment of shoreline changes. *Natural Hazards*, doi:10.1007/s11069-012-0407-y

Dolan, R., B. P. Hayden, P. May, and S. K. May. 1980. The reliability of shoreline change measurements from aerial photographs. *Shore and Beach* 48 (4):22–29.

Esteves, L. S., E. E. Toldo Jr., S. R. Dillenburg, and L. J. Tomazelli. 2002. Long- and short-term coastal erosion in Southern Brazil. *Journal of Coastal Research*, Special Issue 36:273–282.

Fletcher, C. H., R. A. Mullane, and B. M. Richmond. 1997. Beach loss along armored shorelines on Oahu, Hawaiian Islands. *Journal of Coastal Research* 13 (1): 209–215.

Gorman, L., A. Morang, and R. Larson. 1998. Monitoring the coastal environment. Part IV: Mapping, shoreline changes, and bathymetric analysis. *Journal of Coastal Research* 14 (1):61–92.

Hapke, C. J., E. A. Himmelstoss, M. Kratzmann, J. H. List, and E. R. Thieler. 2010. National assessment of shoreline change: Historical shoreline change along the New England and Mid-Atlantic coasts: *U.S. Geological Survey Open-File Report 2010-1118*, 57 p.

IPCC (Intergovernmental Panel on Climate Change). 2014. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R. K. Pachauri and L. A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 p.

Jimenez, J., and A. Sanchez-Arcilla. 1993. Medium-term coastal response at the Ebro delta, Spain. *Marine Geology* 114:105–118.

Jonah, F. E., D. Adjei-Boateng, A. E. Mensah, N. W. Agbo, and R. E. Edziyie. 2015. Assessment of sand and stone mining along the coastline of Cape Coast, Ghana. *Annals of GIS*, doi:10.1080/19475683.2015.1007894

Jonah, F. E. 2015. Managing coastal erosion hotspots along the Elmina, Cape Coast and Moree area of Ghana. *Ocean and Coastal Management*, doi:10.1016/j.ocecoaman.2015.02.007

Kurt, S., A. Karaburun, and A. Demirci. 2010. Coastline changes in Istanbul between 1987 and 2007. *Scientific Research and Essays* 5 (19):3009–3017.

Ly, C. K. 1980. The role of the Akosombo Dam on the Volta River in causing coastal erosion in Central and Eastern Ghana (West Africa). *Marine Geology* 37 (3/4):323–332.

Mackenzie, F. T. 2003. *Our changing planet*. Upper Saddle River, NJ: Prentice Hall.

Magoon, O. T., S. J. Williams, L. K. Lent, J. A. Richmond, D. D. Treadwell, S. L. Douglas, B. L. Edge, L. C. Ewing, and A. P. Pratt. 2004. Economic impacts of anthropogenic activities on coastlines of the United States. Proceedings of the 29th International Conference on Coastal Engineering ASCE, 3022–3035.

Mensah, J. V. 1997. Causes and effects of coastal sand mining in Ghana. *Singapore Journal of Tropical Geography* 18 (1):69–88.

Minerals Commission Ghana. 2011. Geology and minerals resources in Ghana. Minerals Commission, Switchback Road-Residential Area, Accra.

Morton, R. A. 1991. *Accurate shoreline mapping: Past, present, and future*. Proceedings of the Coastal Sediments '91 (Seattle, Washington), pp. 997–1010.

Morton, R. A., T. L. Miller, and L. J. Moore. 2004. National assessment of shoreline change: Part 1: Historical shoreline changes and associated coastal land loss along the U.S. Gulf of Mexico: *U.S. Geological Survey* Open-file Report 2004-1043, 45 p.

NRC (National Research Council). 1990. Committee on Coastal Erosion Zone Management. *Managing Coastal Erosion*. Washington, DC: National Academy Press.

Neal, W. J., D. M. Bush, R. M. T. Webb, J. G. Liboy, and L. Hyman. 1995. *Living with the Puerto Rico shore*. Durham, NC: Duke University Press.

Nicholls, R.J., P. P. Wong, V. R. Burkett, J. O. Codignotto, J. E. Hay, R. F. McLean, S. Ragoonaden, and C. D. Woodroffe. 2007. Coastal systems and low-lying areas. In *Climate Change 2007: Impacts, adaptation and vulnerability*. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, ed. M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden, and C. E. Hanson, 315–356. Cambridge, UK: Cambridge University Press.

Oteng-Ababio, M., K. Owusu, and K. A. Addo. 2011. The vulnerable state of the Ghana coast: The case of Faana-Bortianor. JAMBA: *Journal of Disaster Risk Studies* 3 (2):429–442.

Pajak, M. J., and S. P. Leatherman. 2002. The high water line as shoreline indicator. *Journal of Coastal Research* 18 (2):329–337.

Pilkey, O. H., and E. R. Thieler. 1992. Coastal erosion. SEPM slide set 6, 24 pp. Department of Geology, Duke University, North Carolina.

Sanjaume, E., and J. E. Pardo-Pascual. 2005. Erosion by human impact on the Valencian coastline (E of Spain). *Journal of Coastal Research*, SI 49 (Proceedings of the 2nd Meeting in Marine Sciences), 76–82. Valencia, Spain.

Schlacher, T. A., and L. M. C. Thompson. 2007. Exposure of fauna to off-road vehicle (ORV) traffic on sandy beaches. *Coastal Management* 35:567–583.

Taylor, J. R. 1997. *An introduction to error analysis: The study of uncertainties in physical measurement*. Sausalito, CA: University Science Books.

Thieler, E. R., E. A. Himmelstoss, J. L. Zichichi, and A. Ergul. 2009. Digital Shoreline Analysis System (DSAS), Version 4.0 —An ArcGIS Extension for Calculating Shoreline Change: U.S. Geological Survey Open-File Report 2008–1278.

Thornton, E. B., A. Sallenger, J. C. Sesto, L. Egley, T. McGee, and R. Parsons. 2006. Sand mining impacts on long-term dune erosion in southern Monterey Bay. *Marine Geology* 229:45–58.

Tomazelli, L. J., J. A. Villwock, S. R. Dillenburg, F. A. Bachi, and B. A. Dehnhardt. 1998. Significance of present-day coastal erosion and marine transgression, Rio Grande do Sul, southern Brazil. *Anais da Academia Brasileira de Ciências* 70 (2):221–229.

Valiela, I. 2006: *Global coastal change*. Oxford: Blackwell.

Wong, P. 2003. Where have all the beaches gone? Coastal erosion in the tropics. *Singapore Journal of Tropical Geography* 24 (1):111–132.

Xue, Z., A. Feng, P. Yin, and D. Xia. 2009. Coastal erosion induced by human activities: A northwest Bohai Sea case study. *Journal of Coastal Research* 25 (3):723–733.